Direct Observation of the Alignment of Ferromagnetic Spins by Antiferromagnetic Spins

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INTRODUCTION

The arrangement of spins at interfaces in a layered magnetic material often has an important effect on the properties of the material. One example of this is the directional coupling between the spins in an antiferromagnet (AFM) and those in an adjacent ferromagnet (FM), an effect first discovered in 1956 [1] and referred to as exchange bias. Because of its crucial technological importance for the development of advanced devices such as magnetic read heads [2] and magnetic memory cells [3], this phenomenon has received much attention [4,5]. Despite extensive studies, however, exchange bias is still poorly understood, which is largely due to the lack of techniques capable of providing detailed information on the arrangement of magnetic moments near interfaces. Here we present results obtained with polarization dependent x-ray magnetic dichroism spectromicroscopy that separately reveal the micromagnetic structure on both sides of a AFM/FM interface using the photoelectron emission microscope (PEEM2) located at beam line 7.3.1.1 of the Advanced Light Source (ALS) [6]. A detailed description of the results reported here can be found elsewhere [7].

EXPERIMENT

We investigated a thin Co film on top of a 40 nm $LaFeO_3$ film grown on $SrTiO_3$ (001). Plan view electron-diffraction and conventional TEM analysis show that the epitaxial $LaFeO_3$ film consists of two microscopic crystallographic domains characterized by orientations of the $LaFeO_3$ **c**-axis along the [100] and [010] directions in the $SrTiO_3$ surface plane [8]. The Co film, grown in form of a stepped wedge, was deposited in situ at room temperature and capped with a 1 nm Pt layer to prevent its oxidation. All measurements, reported here, were performed on as-grown samples. Since the samples were not set in a magnetic field they did not exhibit a macroscopic exchange bias [4,5]. However, our ability of probing the magnetic configuration spatially resolved allowed us to observe local bias effects, which average to zero macroscopically.

Spectromicroscopy studies were carried out using the PEEM2 instrument at the Advanced Light Source (ALS) in Berkeley [6]. PEEM is a full field imaging technique where X-ray excited electrons are used to form an image of the sample surface as a function of the X-ray photon energy and polarization. This so-called spectromicroscopy method combines two concepts: X-ray absorption spectroscopy and electron microscopy. Contrast can be due to a number of mechanisms including topographic, elemental, chemical, polarization, X-ray magnetic linear (XMLD) and circular dichroism (XMCD) contrast.

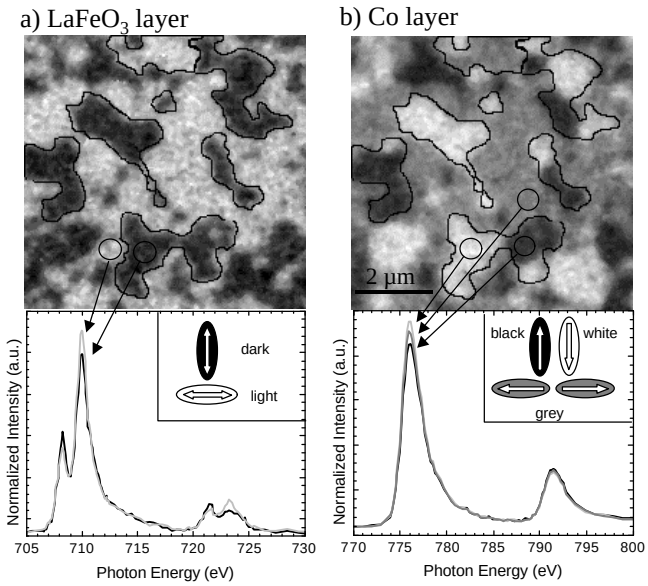

Figure 1. Images and local spectra from the antiferromagnetic and ferromagnetic layers for 1.2 nm Co on $LaFeO_3/SrTiO_3(001)$. (a) Fe L-edge XMLD image and (b) Co L-edge XMCD image. The contrast in the images arises from antiferromagnetic domains in $LaFeO_3$ (a) and ferromagnetic domains in Co (b) with in-plane orientations of the antiferromagnetic axis and ferromagnetic spins as indicated below the images. The spectra shown underneath were recorded in the indicated areas and illustrate the origin of the intensity contrast in the PEEM images.

Fig. 1 shows images of the domain structure in the AFM $LaFeO_3$ film and in a 1.2 nm thick FM Co layer on top of the very same substrate region. The XMLD and XMCD spectra recorded in single domains, shown underneath, reveal the spectroscopic origin of the AFM and FM contrast. Comparison of the in-plane projection of the AFM axis and the FM spin direction, illustrated below the images, reveals that the FM Co spins are aligned parallel to the in-plane projection of the AFM axis. This alignment is caused by coupling to uncompensated spins at the $LaFeO_3$ surface.

The exchange coupling at the $Co/LaFeO_3$ interface causes a local exchange bias in individual Co domains. This was revealed by local remanent hysteresis loops, calculated from the field dependent XMCD contrast in a series of images, which show a repeatable loop shift for single domains of up to 30 Oe, whereas the spatially averaged bias is zero. The lack of bias in the averaged loop is expected, because the studied sample was not set in a magnetic field. The setting procedure would shift the balance of the microscopically biased domains, resulting in a preferred macroscopic spin direction, i.e. exchange bias.

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